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Trends in Analytical Chemistry Education Research: A Biblometric Analysis

Analitik Kimya Eğitimi Araştırmalarındaki Eğilimler: Bibliyometrik Bir Analiz

Doğan DOĞAN[1]

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Abstract: Analytical chemistry is a sub-branch of chemistry that focuses on the qualitative and quantitative analyses of chemical compositions of substances. Bibliometric analysis is an important tool to identify research gaps and research trends in a particular field. Although some bibliometric studies focusing on analytical chemistry research have been found in the current literature, no study focused on analytical chemistry education research has been found yet. Therefore, in this study, the current state of analytical chemistry education research was attempted to be revealed through a bibliometric analysis of relevant articles in the Web of Science (WoS) database between 2000 and 2024. The data collection process was conducted in accordance with the current PRISMA standards, and a total of 742 articles were included in the scope of the research. The data were analyzed using Microsoft Excel, Harzing's Publish or Perish, VOSviewer, and Biblioshiny software. The results showed that the number of publications has increased significantly since 2010, with a peak of 81 articles in 2021 and 1,916 citations in 2023. The United States was the leading country with 1,061 publications, while the National University of Singapore ranked first among the institutions with 24 articles. The most productive journal was the Journal of Chemical Education, with 693 articles published. The article by Elgrishi et al. (2018) was the most influential article; Endler Marcel Borges was the most prolific author, and the keyword "analytical chemistry" was the most frequently used keyword. Overall, these results show that since the year 2010, there has been a growing interest in analytical chemistry education research.

Keywords: Analytical Chemistry Education, Research Trends, Bibliometric Analysis

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Öz: Analitik kimya, maddelerin kimyasal bileşimlerinin nitel ve nicel analizlerine odaklanan, kimyanın bir alt dalıdır. Bibliyometrik analiz, belirli bir alandaki araştırma boşluklarını ve eğilimlerini belirlemek için önemli bir araçtır. Mevcut literatürde analitik kimya araştırmalarına odaklanan bazı bibliyometrik çalışmalar bulunmasına karşın, analitik kimya eğitimi araştırmaları üzerine odaklanan bir çalışmaya henüz rastlanmamıştır. Bu nedenle, bu çalışmada, 2000-2024 yılları arasında Web of Science (WoS) veri tabanındaki ilgili makalelerin bibliyometrik analizi yoluyla analitik kimya eğitimi araştırmalarının mevcut durumu ortaya konulmaya çalışılmıştır. Veri toplama süreci güncel PRISMA standartlarına uygun olarak yürütülmüş ve araştırma kapsamına toplam 742 makale dahil edilmiştir. Veriler Microsoft Excel, Harzing's Publish or Perish, VOSviewer ve Biblioshiny yazılımları kullanılarak analiz edilmiştir. Sonuçlar, yayın sayısının 2010 yılından bu yana önemli ölçüde arttığını, 2021 yılında 81 makale ve 2023 yılında 1.916 atıf ile zirveye ulaştığını göstermiştir. Amerika Birleşik Devletleri 1.061 yayınla lider ülke olurken, Singapur Ulusal Üniversitesi 24 makale ile kurumlar arasında ilk sırada yer almıştır. En üretken dergi, 693 makale yayılanan Journal of Chemical Education dergisi olmuştur. Elgrishi ve arkadaşlarının (2018) makalesi en etkili makale; Endler Marcel Borges en üretken yazar ve "analytical chemistry" kelimesi en sık kullanılan anahtar kelime olmuştur. Genel olarak, bu sonuçlar 2010 yılından bu yana analitik kimya eğitimi araştırmalarına olan ilginin giderek arttığını göstermektedir.

Anahtar Kelimeler: Analitik Kimya Eğitimi, Araştırma Eğilimleri, Bibliyometrik Analiz

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[1] Sorumlu Yazar: Dr. Öğr. Üyesi Doğan DOĞAN, Bolu Abant İzzet Baysal Üniversitesi, Matematik ve Fen Bilimleri Eğitimi Bölümü, ddogan@ibu.edu.tr, https://orcid.org/0000-0001-7889-329X

1. INTRODUCTION

Analytical chemistry is an important branch of chemistry which deals with the qualitative analysis of ionic species as well as chemical compounds and mixtures, and the quantitative determination of their concentration levels in a given sample (Kaushik & Kumar, 2023; Soffiantini, 2021). This field basically involves the generation of precise and accurate information on the chemical composition of a sample, which is vital in scientific research, quality control processes and regulatory compliance (Skoog et al., 2021; Wenclawiak et al., 2010). Given its complexity and specialized nature, analytical chemistry education aims to provide students with technical knowledge that extends beyond what is covered in general chemistry courses. In recent years, the rapid increase in the number of scholarly publications within this field highlights the need for the conduct of systematic reviews or bibliometric analysis to synthesize existing knowledge and identify current research trends. Such efforts are essential to support educators, curriculum developers and new researchers in the field.

Analytical chemistry has evolved to include newer and sophisticated analytical methods like spectroscopy, chromatography, electrochemical analysis, and mass spectrometry due to increasing demand for speedy and accurate analytical results caused by the rapid advancement of scientific research and technological development around the world (Skoog et al., 2017). It plays a key role in food science, environmental science, and health sciences, and is also important in fields such as nanotechnology and biotechnology. For example, the analysis of water and air samples helps determine contamination of the environment whereas the pharmaceutical industry assesses the purity and appropriate dosage of active ingredients. Furthermore, the invention of automated and artificial intelligence-enhanced analytical techniques is a revolutionary advancement in this field as they improve efficiency in analyzing complex data and facilitate better decision-making. Cardoso Rial (2024) noted that artificial intelligence can significantly improve analytical chemistry practices but emphasized the need for clear ethical guidelines and interdisciplinary collaboration to ensure its responsible use. Determination of the extent to which these developments are reflected in the analytical chemistry education research can provide guidance for future studies in the field.

Analytical chemistry education plays a critical role in shaping future experts who will drive innovation in the field, both in terms of science and chemistry education. Traditional analytical chemistry education at universities includes lectures and lab hours. The content of lectures and the conduct of laboratory experiments do vary significantly based on the available resources (Wenzel et al., 2024). Yet, the problems encountered in the real world, as well as the developments in instrumental analytical techniques, necessitate an interdisciplinary approach to analytical chemistry education. It can be said that current analytical chemistry education ought to furnish the students with not only the skills to use modern equipment but also with a sound understanding of data analysis and interpretation and the ability to solve complex analytical problems. Moreover, as the world is becoming more global in industrialization, students should also be exposed to the latest global trends, including but not limited to multidisciplinary interaction and best practices in analytical approaches. Education in analytical chemistry is thus needed to evolve with time to remain relevant and attractive.

A lot of universities offer undergraduate programs across faculties, such as science, engineering, health sciences, and education. Most of these programs have analytical chemistry courses which are compulsory. Instrumental Analysis and Instrumental Analysis Laboratory are other major courses in these programs. Over the years many textbooks have been published in this field, textbooks like Fundamentals of Analytical Chemistry (Skoog et al., 2021), Principles of Instrumental Analysis (Skoog et al., 2017), Quantitative Chemical Analysis (Harris, 2015), and Analytical Chemistry (Christian et al., 2013) sufficiently encompass analytical chemistry topics which ensure that students and professionals can find relevant information on various analytical techniques and methodologies. These textbooks also emphasize how theoretical knowledge can be applied in real-world scenarios and reflect the recent advances in analytical chemistry, which are critical for students and professionals in the field. Despite the usefulness of these books, some studies indicate that analytical chemistry topics are difficult for students due to their abstract nature (He et al., 2012; Masania et al., 2018). In this case, to improve analytical chemistry education and to identify the main areas of improvement, it is necessary to examine the research on analytical chemistry education in the relevant literature.

Bibliometric analyses and systematic reviews of publications on analytical chemistry education can reveal which analytical themes have been adequately addressed earlier and whether there are opportunities to learn about new areas that require further research. However, when the relevant literature was examined, it was seen that there was no bibliometric study on analytical chemistry education research, but there were some studies that focused on different areas of analytical chemistry and analytical chemistry education research (Benhander, 2024; Hupp et al., 2024; Mao et al., 2022; Shao et al., 2022; Shidiq et al., 2021; Verma, 2017). Verma (2017) categorized and evaluated research publications from 20 peer-reviewed analytical chemistry journals from the most prolific Indian universities and institutes between 2001 and 2016 using the Scopus database to provide a perspective on analytical chemistry. The overall performance of analytical chemistry research was also compared to chemistry research in the selected cities of India and found to be only 6.5%. However, it was determined that the research area showed a growing performance by year. Moreover, it was shown that, among the 21 research centers in the country, the analytical techniques used in the research publications also represented regional preferences. Hupp, Kovarik, and McCurry (2024) used SciFinder for keyword searches to quantify the number of citations of general research papers and education articles per year for the analytical research themes of chemometrics, microfluidics, and microcontrollers. Shidiq et al. (2021) employed the VOSviewer software to perform a bibliometric examination of 128 scholarly articles from Google Scholar concerning the application of fundamental spectrophotometers within STEM education that were published during the period from 2001 to 2016. Another bibliometric study conducted by Mao et al. (2022) on the role of electrochemical biosensors in SARS-CoV-2 analyzed 254 relevant research papers in terms of different countries and institutions and keywords. The function of electrochemical biosensors was the subject of another bibliometric analysis by Shao et al. (2022), who analyzed a total of 865 papers obtained from the WoS core database using CiteSpace. Benhander (2024) carried out bibliometric analysis on another research field of analytical chemistry, namely microextraction techniques in drug analysis using the Scopus database and VOSviewer program. The analysis includes a total of 1,321 articles from 157 academic publications and covers the years 2014–2023. According to the results obtained, interdisciplinary cooperation between many fields such as chemistry and biochemistry is essential for making progress in microextraction techniques.

In summary, the above studies show that various bibliometric analyses have been performed on different research fields or subbranches of analytical chemistry, but to the best of our knowledge, there is not yet any comprehensive systematic review or bibliometric analysis research on analytical chemistry education. However, the increasing number of scientific publications on analytical chemistry education makes it necessary to fill this gap in the current literature. Accordingly, the primary objective of the present study is to explore the current state of analytical chemistry education using bibliometric analysis of papers retrieved from the WoS database from 2000 to 2024. It is intended that this study will serve as a valuable resource for future research and insights in the field of analytical chemistry education, which may also lead to curriculum development studies and innovative applications in this field.

2. METHOD

2.1. Research Design

The present study tries to analyze the research trends in analytical chemistry education between 2000 and 2024. For this purpose, bibliometric analyses are conducted. Bibliometric analysis is a quantitative technique used to analyze various bibliographic data such as research-based publications and citations within specific scientific disciplines. In bibliometric analyses, complex data from an electronic database such as Web of Science, Scopus, and Google Scholar are collected, analyzed statistically, converted into models, which are then visualized and interpreted with the help of visualization tools such as VOSViewer and Biblioshiny (Aria & Cuccurullo, 2017; van Eck & Waltman, 2014). In addition, bibliometric analysis contributes to the monitoring of the productivity of researchers through the usage of numerical data such as citation counts and h-index. Moreover, it helps in comprehensive mapping of studies for the identification of new study areas, facilitating interdisciplinary research collaborations, identifying emerging research trends and thematic priorities in a particular field, and making scientific evaluations more consistent and objective.

2.2. Data Collection

In the present study, data collection process was carried out according to the steps outlined in the updated version of PRISMA standards (Page et al., 2021), as presented in Figure 1.

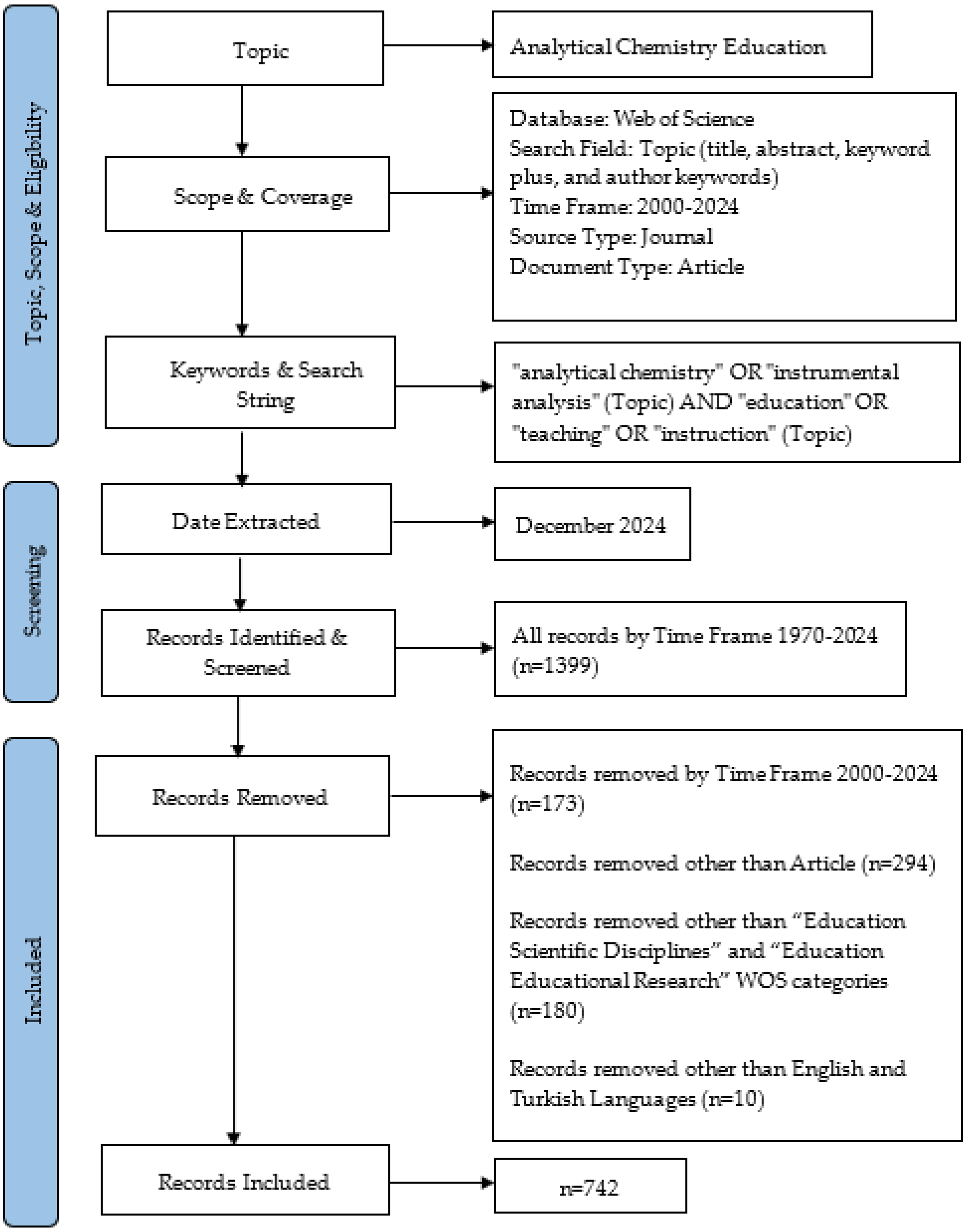

Figure 1. *The search strategy with PRISMA flow diagram*

The Web of Science (WoS) database was selected as the primary data source for obtaining bibliographic indicators. It is widely acknowledged that this database is considered to contain internationally accepted high-quality publications (Birkle et al., 2020; Falagas et al., 2008). Once the database to be used for the collection of research data had been selected, the search strategy was determined. To reach the most articles related to analytical chemistry education, it was decided that a search under the topic heading would be more fruitful than a search under the title heading in WoS database. This is because a search under the topic heading in the WoS database also encompasses a search for the subheadings of title, abstract, keyword plus, and author keywords. Conversely, while the lack of coverage of all articles related to analytical chemistry education may be perceived as a limitation of the research, it is anticipated that this will not markedly alter the broader picture of the field that is sought to be presented within the context of the research purpose.

The field of analytical chemistry education encompasses the education of fundamental principles of both classical analytical techniques, such as gravimetric and volumetric analysis, and instrumental analytical techniques. Accordingly, a search was conducted in the WoS database under the topic heading, combining the terms "analytical chemistry" and "instrumental analysis" with the keywords "education," "teaching," and "instruction." The initial search generated a total of 1,399 publications covering the period between 1970 and 2024. Then, the publication year range in this research was set to 2000-2024, and a total of 1,226 publications comprising articles, proceedings papers, educational material, meeting abstracts, etc., were obtained. After that, the publication type was set to article, and a total of 932 data records were obtained. Since it was thought that the categories most closely related to analytical chemistry education among the WoS categories are the 'Education Scientific Disciplines' and 'Education Educational Research' categories, the dataset was further refined categorically, leaving 752 data records. A final refinement of the dataset in terms of language resulted in the generation of a dataset containing 742 records. The records were then rigorously reviewed by two experts in chemistry education to determine whether they were appropriate for inclusion in the study. During the review process, each reviewer independently examined the records, and after completing their individual screening, the results were compared. Since it was found that all these article records focused on diverse aspects of analytical chemistry education, all 742 articles remained in the final dataset upon the consensus reached between both reviewers.

2.3. Data Analysis

The empirical data obtained from this study, which consists of 742 scholarly articles from the WoS database, are stored on the hard disk of the computer as tab-delimited and BibTeX files for further analysis. The record content option displayed in the "Full Record and Cited References" was chosen to carry out the process. Both performance analysis and science mapping were employed to achieve the objectives of the study. Performance analysis was carried out using Microsoft Excel, Harzing's Publish or Perish, and RStudio's Biblioshiny software applications to describe the general characteristics of the reviewed literature. Science mapping was performed using VOSviewer. The function of Harzing's Publish or Perish is to assess the h-index, g-index, citation counts, and other metrics, which measure the impact of the academic publications and the author's academic scholarly productivity, whereas the function of VOSviewer is to visualize academic networks, author collaborations, keyword networks, citation and publication link networks, and exploration of trends, clusters, and the network structure of a research domain (Harzing, 2023; van Eck & Waltman, 2010). The Biblioshiny application is a web interface of an R package for science mapping analysis (Aria & Cuccurullo, 2017). It allows the users to analyze with ease without writing any R codes.

3. RESULTS AND DISCUSSION

As stated in the preceding method section, this section describes the findings of a thorough bibliometric study of scholarly articles relevant to the field of analytical chemistry education. To this end, first, a descriptive analysis of the articles published on analytical chemistry education was conducted on the obtained dataset. Then, it was followed by research productivity in terms of publication and citation trends, the identification of the most productive countries and institutions that have published the highest number of articles on the subject, the most influential journals, the most influential articles, the most productive authors, and a bibliometric mapping analysis of analytical chemistry education research.

3.1. Performance Analysis

The study's dataset was descriptively analyzed via Harzing's Publish and Perish and the Biblioshiny softwares. The results are summarized and presented in Table 1.

Table 1.
Descriptive Analysis of the Dataset

Description	Results
Timespan	2000-2024
Journals	25
Articles	742
Annual Growth Rate %	11.4
Document Average Age	6.59
Average citations per documents	15.62
Author's Keywords (DE)	763
Authors	2582
Single-authored documents	104
Documents per Author	3.64
Co-Authors per Document	3.93
International co-authorships %	7.143
h-index	41
g-index	75

As depicted in Table 1, this study is based on 742 publications in the form of articles retrieved from the Web of Science database on analytical chemistry education published in 25 different journals between 2000 and 2024. The annual growth rate of publications is 11.4%, which indicates that the interest of researchers in this area is growing at a rapid pace. The research area consists of contributions from 2,582 authors who were part of multi-authored studies, but only 7.143% of the articles have been co-authored internationally. This implies that there is not much collaboration between the authors from different countries. On the other hand, the average citations per document and h-index of all the documents are 15.62 and 41, respectively, which are indicative of the effectiveness of research and publication performance in the field of analytical chemistry education.

3.1.1. *Publication and citation trends*

Table 2 presents the results of the annual publication and citation trends. As can be seen from this table, there is no significant change in the number of publications and citations from 2000 to 2010. It is also seen from the table that the first article in the field of analytical chemistry education appeared in 2003, and the number of publications gradually increased towards 2010, while the number of citations followed a zigzag pattern. Nevertheless, the number of articles produced between 2010 and 2014 increased rapidly. This increasing tendency peaked with 81 articles published in 2021, despite occasional declines in 2015, 2017, 2019, and 2022. On the other hand, there has been a sharp rise in the number of citations, which reached a peak of 1,916 citations in 2023. Furthermore, it is early to comment on the drop in the number of articles produced in 2024, as the year 2024 has not ended yet. These findings indicate that researchers have shown a notable and marked interest in the field of analytical chemistry education since 2010. Likewise, Pabuçcu-Akış (2025) conducted a bibliometric analysis of the literature on the use of innovative technology tools in organic chemistry education. The analysis revealed that the first article published in the field appeared in 2014 and that the highest number of publications and citations were reached in 2020, 2023, and 2019, respectively. Another study carried out by Arifiani and Irwanto (2024) revealed that the lowest number of publications appeared in 2012, whereas the highest number of publications was observed in 2021. Ayna and Şen (2024) conducted a bibliometric analysis of inquiry-based learning in chemistry education and determined that there has been an increase in the number of papers since 2011, with the majority of studies completed in 2020 and 2021. These results confirm that studies in chemistry education and related fields have shown an upward trend since the 2010s, as in our study.

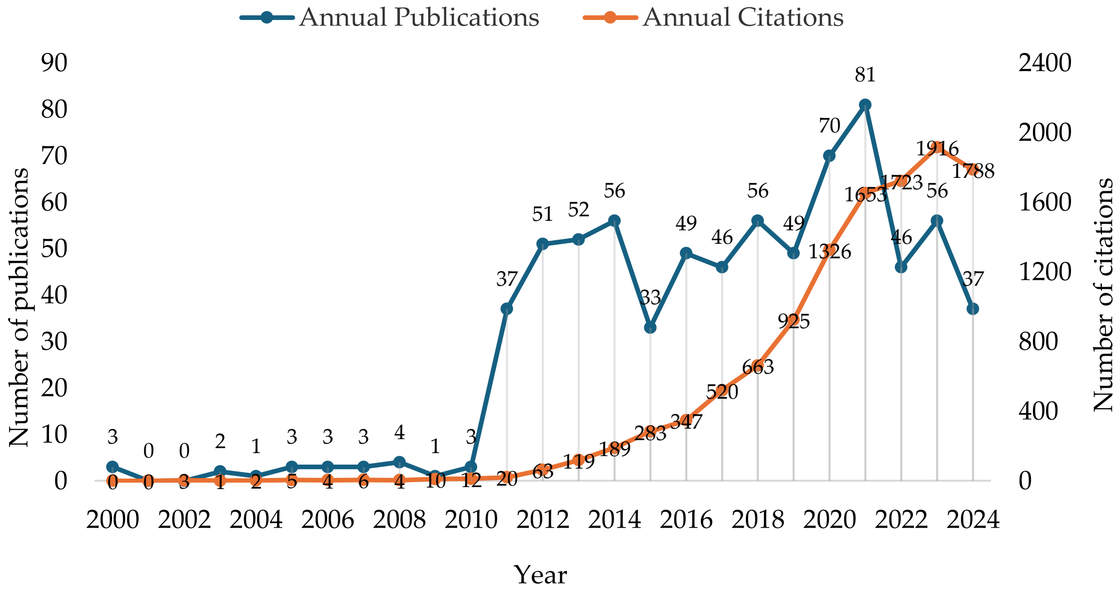

Figure 2. *Number of publications and citations per year*

3.1.2. *Most productive countries*

The most productive countries in the field of analytical chemistry education research were identified through Biblioshiny analysis, and the results are shown graphically in Figure 3.

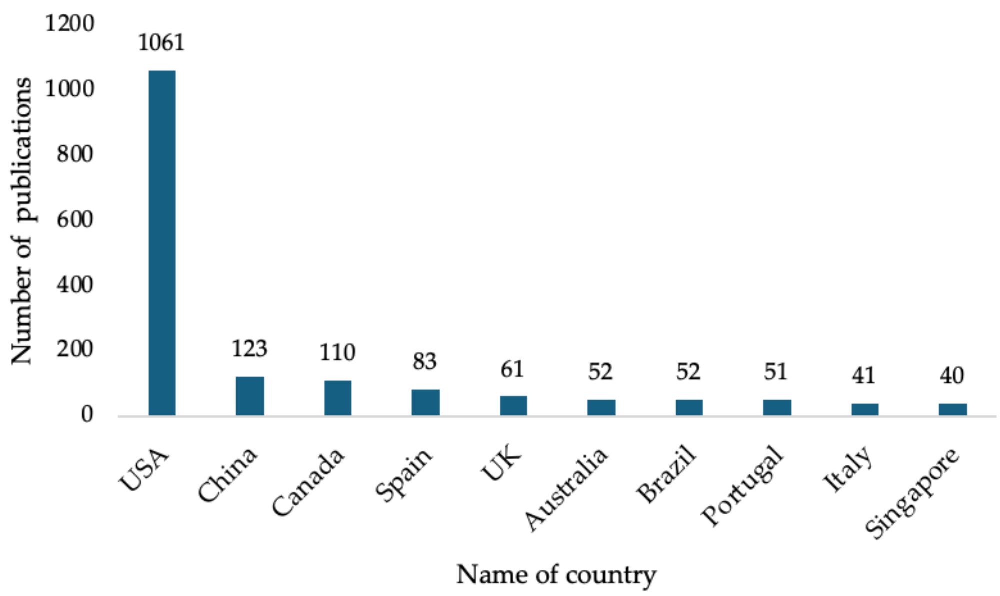

Figure 3. *The most productive countries*

Figure 3 shows the list of the 10 most productive countries in the field. As shown in Figure 3, the USA dominates the field with the highest number of publications (n=1061), followed by China, Canada, Spain, and the UK. The remaining countries in the list exhibit similar productivity levels, with a range of 52–40 publications. The fact that most publications in this field are of USA origin may be related to the fact that one of the oldest and most established journals in the field of chemistry education, the Journal of Chemical Education, which also contains the majority of publications on analytical chemistry education (Table 2), is of USA origin. Similarly, several studies have demonstrated that the USA is the nation that contributes the most to publications (Arifiani & Irwanto, 2024; Ayna & Şen, 2024; Hassan et al., 2022; Tosun, 2024).

3.1.3. *Most productive institutions*

Figure 4 depicts the top 10 institutions whose authors contributed most to the analytical chemistry education research publications.

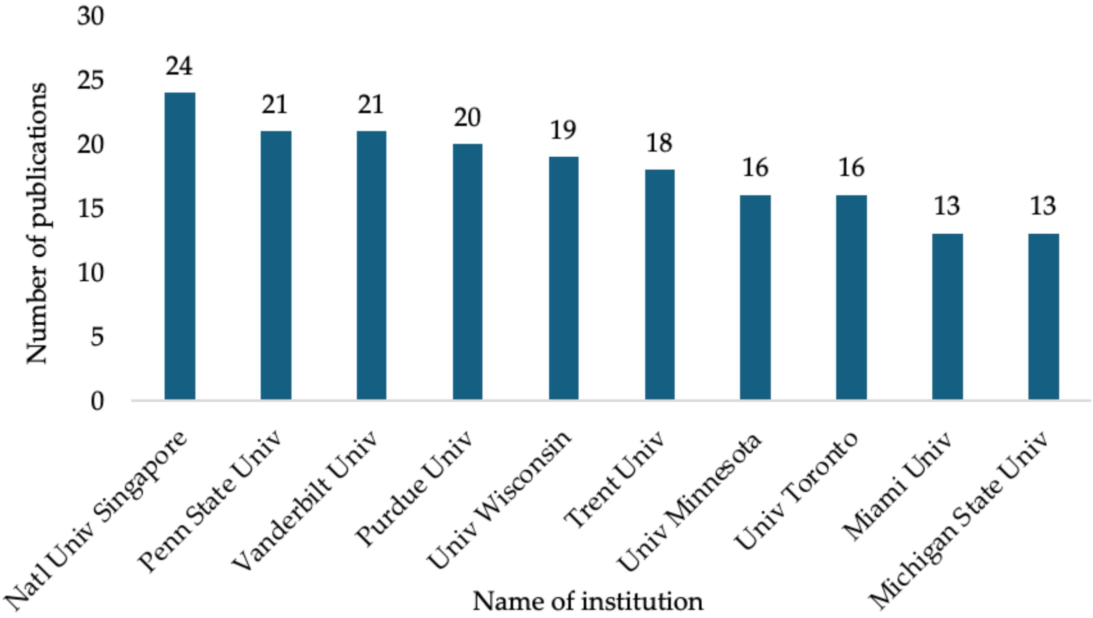

Figure 4. *The most productive instutitions*

The National University of Singapore (n=24) held the leading position, followed by Penn State (n=21), Vanderbilt (n=21), Purdue (n=20), Wisconsin (n=19), Trent (n=18), Minnesota (n=16), and Toronto (n=16) universities (Figure 4). The last two universities, namely Miami and Michigan State universities, exhibit the same productivity levels, with 13 publications. An examination of the list indicates that a substantial proportion of the institutions are affiliated with universities that possess significant recognition within the United States. The National University of Singapore and the University of Toronto are from Singapore and Canada, respectively. According to Scimago Institutions Rankings in 2024 (Research and Innovation Rankings - Singapore 2024), the overall ranking of The National University of Singapore in all subject areas is one compared to the 36 ranked institutions in Singapore. According to the Times Higher Education (THE) World University Rankings 2025 (*World University Rankings*, 2024), The National University of Singapore is in 17th place, which indicates it is a successful research institution worldwide. Therefore, it is understandable that it occupies the highest position in the list of contributions to the analytical chemistry education research productivity.

3.1.4. *Most influential journals*

The collection of 742 articles used in this study was published by 25 different journals (Table 1). Table 2 lists the top impactful journals in the field with an h-index over one. Therefore, 16 additional journals with h-indices of 1 were excluded from Table 2. Besides, Table 2 shows that almost all the publications (97.44%) in the field were published in these nine journals. In terms of h-index value, the Journal of Chemical

Education is the top influential journal (n=39), followed by Chemistry Education Research and Practice (n=6), Biochemistry and Molecular Biology Education (n=3), and Education for Chemical Engineers (n=3). The h-index metric elucidates the influence of a scholarly journal by indicating the frequency with which its published articles have been cited a specified number of times, which means that it significantly influences the citation rate of that journal (Braun et al., 2006; Muriyatmoko & Putra, 2018). Furthermore, as seen from Table 2, the Journal of Chemical Education is also the most influential journal in terms of publication volume, with a total number of 693 publications. Several bibliometric analyses pertaining to organic chemistry and biochemistry education additionally indicate that a substantial proportion of documents are published in the Journal of Chemical Education (Barbosa & Galembeck, 2022; Hassan et al., 2022; Pabuçcu-Akış, 2025). These findings demonstrate that the Journal of Chemical Education ranks among the most influential journals in terms of undergraduate chemistry education.

Table 2.

Top Influential Journals in the Field

Source	NP	TC	h-index
Journal of Chemical Education	693	11011	39
Chemistry Education Research and Practice	12	186	6
Biochemistry and Molecular Biology Education	3	32	3
Education for Chemical Engineers	3	144	3
American Journal of Pharmaceutical Education	2	27	2
Chemistry Teacher International	3	14	2
Education Sciences	3	7	2
Journal of Baltic Science Education	2	14	2
Research in learning Technology	2	54	2

NP: Number of Publications, TC: Total Citations. Journals are listed according to NP

3.1.5. *Most influential articles*

Table 3 lists the top 10 globally cited articles in the field of analytical chemistry education research.

Table 3.

Top 10 Global Cited Articles in the Field

Article DOI Number	Author/year	Source	TC	TCY
"https://doi.org/10.1021/acs.jchemed.7b00361"	Elgrishi et al., 2018	JCE	1928	275.43
"https://doi.org/10.1021/acs.jchemed.5b00483"	Ma et al., 2016	JCE	295	32.78
"https://doi.org/10.1016/j.ece.2021.01.012"	Lapitan et al., 2020	ECE	134	26.80
"https://doi.org/10.1021/acs.jchemed.5b00654"	Grasse et al., 2016	JCE	123	13.67
"https://doi.org/10.1021/acs.jchemed.5b00844"	Kuntzleman et al., 2016	JCE	92	10.22
"https://doi.org/10.1021/ed300567p"	Kehoe et al., 2013	JCE	88	7.33
"https://doi.org/10.1021/ed200685p"	He et al., 2012	JCE	87	6.69
"https://doi.org/10.1021/acs.jchemed.6b00262"	Grinias et al., 2016	JCE	84	9.33
"https://doi.org/10.1021/ed400838n"	Asheim et al., 2014	JCE	63	5.73
"https://doi.org/10.1021/acs.jchemed.0c00604"	Destino et al., 2020	JCE	60	12.00

TC: Total Citations per Year, JCE: Journal of Chemical Education, ECE: Education for Chemical Engineers

It is evident from Table 3 that most of the studies are generally focused on spectroscopy education. However, the most cited article by Elgrishi et al. (2018) is related to electrochemistry education, which provides a comprehensive guide to cyclic voltammetry for educational endeavors and research purposes. In this study, the researchers provided simple training modules for students for a better understanding of the technique and encouraged self-instruction. The highest citation count received by this study indicates that the subject of cyclic voltammetry is one of particular interest to the research community. On the other hand, when TC values are used as an indicator of a publication's effect alongside TCY values, which do not account for the year effect, Elgrishi et al. (2018)'s paper is once again the most influential article in the ranking. However, when a ranking is made according to the TCY values, the study by Destino & Cunningham (2020) is ranked fifth, ahead of the study by Kuntzleman & Jacobson (2016). Destino & Cunningham (2020) designed an inquiry-oriented colorimetry experiment for learners during the COVID-19 pandemic, which is versatile, practical, requires minimal resources, and fosters critical thinking and engagement in the experimental design process. The high citation rate of recent studies in Table 3 is consistent with the findings of Figure 2, which indicate an increasing trend towards analytical chemistry education research since the 2010s.

3.1.6. *Most productive authors*

Table 4 shows that the most productive author is Borges, EM, with nine articles (1.213%) published. Seven authors have published five articles (0.674%), followed by Chohan, BS, and Bretz, SL, each with four (0.539%) publications. However, when considering total citations per number of publications (TC/NP), the rankings shift, with Grinias, JP taking first place (33.6), Borges, EM in second (23.6), and Fung, FM in third (21.4). Overall, based on the data presented in Table 4, it can be concluded that the most prolific authors are Borges, EM, Grinias, JP, and Fung, FM. Borges centered his research on utilizing laboratory experiments to enhance educational outcomes (Filgueiras et al., 2021; Sidou & Borges, 2020; Silva de Souza & Borges, 2023), while Grinias concentrated on incorporating open-source solutions, Augmented Reality (AR), and web-based competitive quizzes to foster interactive learning (Grinias, 2017; Grinias & Smith, 2020; Naese et al., 2019). On the other hand, Fung explored the potential of emerging technologies such as drones, mobile gaming applications, and web-based virtual reality (VR) platforms (Fung et al., 2019; Fung & Watts, 2017; Koh & Fung, 2018) to advance the teaching of analytical chemistry, aiming to provide students with innovative learning experiences.

Table 4.
Top 10 Most Productive Authors in the Field

Author	NP	% of 742	TC	TC/NP
Borges EM	9	1.213	212	23.6
Grinias JP	5	0.674	168	33.6
Fung FM	5	0.674	107	21.4
Schwarz G	5	0.674	97	19.4
Dickson-Karn NM	5	0.674	70	14
Hossain MM	5	0.674	38	7.6
Smith GC	5	0.674	38	7.6
Dabke RB	5	0.674	25	5
Chohan BS	4	0.539	96	24
Bretz SL	4	0.539	27	6.75

NP: Number of Publications; TC: Total Citations

3.2. Science Mapping

Bibliometric studies employ the science mapping technique, which is very important for understanding the structure and dynamics of knowledge in a particular field (Donthu et al., 2021). This technique uses various bibliometric approaches, such as co-authorship analysis, co-occurrence analysis, and bibliographic coupling to create maps showing the relationships between disciplines, authors, and research trends (Bota-Avram, 2023).

3.2.1. *Co-citation analysis of journals*

Co-citation analysis was performed with the sources that possess a minimum of 20 citations to understand the general structure of the research domain of analytical chemistry education and the distinctive features of the scholarly journals that are frequently co-cited within this domain (Martins et al., 2024). Among the 5,363 sources examined, 71 initially satisfied the citation threshold, yielding 11 distinct clusters. Upon adjusting the minimum cluster size to 3 and refreshing the layout, the number of clusters subsequently decreased to 7. The ultimate bibliometric map generated is presented in Figure 5.

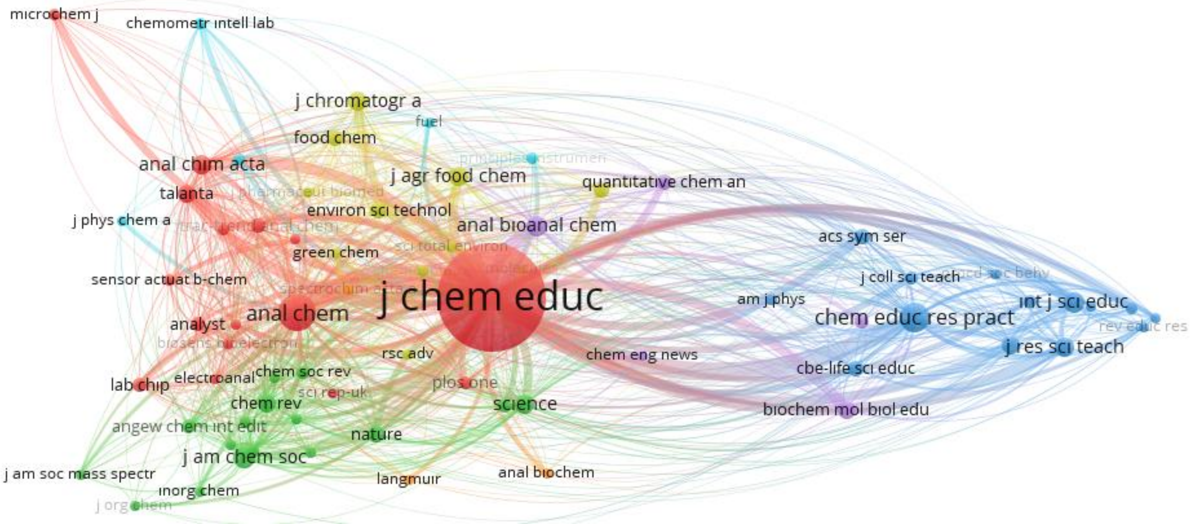

Figure 5. *Co-citation (unit of analysis: journals)*

Figure 5 shows that 71 journals can be clustered into seven different clusters having a total of 1,565 links with a total link strength of 57,029. As shown in the figure, the most frequently co-cited journal is the Journal of Chemical Education, which was co-cited 7,253 times and with a total link strength of 42,219 in the red cluster. This journal also has the strongest links in terms of citations with other chemistry-related and chemistry education journals, such as Analytica Chimica Acta (link strength 1,483), Talanta (link strength 1,444), Chemical Education Research and Practice (link strength 3,783), International Journal of Science Education (link strength 1,310), and Journal of Research in Science Teaching (link strength 1,279). The second and third most frequently co-cited journals are Analytical Chemistry and Chemical Education Research and Practice, with 511 and 295 citations, respectively, which are in the red and blue clusters. Following these journals, the International Journal of Science Education (in the blue cluster), Analytica Chimica Acta (in the red cluster), Journal of Research in Science Teaching (in the blue cluster), Analytical and Bioanalytical Chemistry (in the purple cluster), Journal of the American Chemical Society (in the green cluster), Journal of Chromatography A (in the yellow cluster), and Journal of Agricultural and Food Chemistry (in the yellow cluster) were the next most highly cited journals, each with more than 100 citations. These results imply that research papers in the field of analytical chemical education that are published in these journals share certain thematic similarities. Furthermore, Figure 5 also demonstrates that journals which are directly related to chemistry education are grouped within the blue cluster and that there are strong citation relationships between them. Conversely, journals related to the chemistry discipline are grouped within different clusters, such as red, yellow, and green. However, the Journal of Chemical Education has strong citation relationships with all the other journals and is located in the center. The greater the number of shared citations, the stronger the link between the corresponding documents (Pedraja-Rejas et al., 2024).

3.2.2. *Co-authorship analysis of authors*

Co-authorship analysis explores researchers' social networks through the number of co-authored publications, which is regarded as a better measure of social relationships than other measures (Bota-Avram, 2023; Maral, 2024). To reveal the social interactions between authors contributing to the field of analytical chemistry education research, a visual analysis was performed using VOSviewer software, and the results are presented in Figure 6.

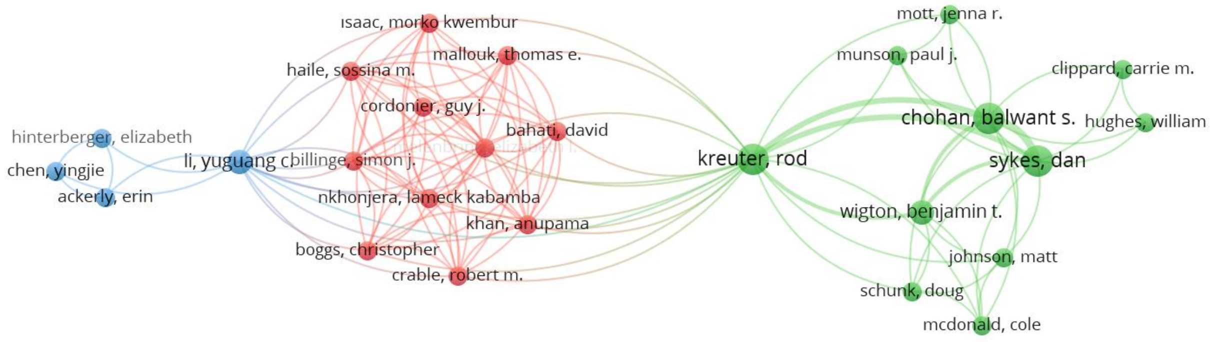

Figure 6. *Co-authorship (unit of analysis: authors)*

Preliminary analysis revealed that 2416 authors participated in the writing of 742 articles. Similar author names were merged in a theasure file, and the analysis was repeated considering a minimum threshold of one document and 10 citations per author, which then resulted in a set of 26 authors who met the threshold. Figure 6 shows how the social interactions between the 26 authors were established. It can be seen from the figure that the researchers gathered in three different clusters, namely light blue (4 items), red (11 items), and green (11 items). The authors within each cluster exhibit a significant degree of interaction. However, authors in different clusters may also engage in collaborative endeavors, albeit with diminished frequency (Koçak & Soylu, 2023). In this regard, Kreuter, R., who is in the green cluster and has the highest total link strength value (n=25), has collaborated with all the members of the red cluster and Li, YC. in the light blue cluster. A close analysis of the Figure 6 reveals that the most prolific collaborators in the field of research on analytical chemistry education are as follows: Kreuter, R., Chohan, BS., Skyes, D., and Li, YC. Among these authors, Kreuter, R., Chohan, BS., and Skyes, D. have collaborated on 4 publications, and Li, YC has on 2 publications. The remaining authors in the figure have only published a single article collectively. These results demonstrate that the number of authors collaborating is quite limited, and their collaboration is not at the expected level, which is in parallel with similar studies (Ayna & Şen, 2024; Hanifa et al., 2024; Pabuçcu-Akış, 2025).

3.2.3. *Co-authorship analysis of countries*

Country co-authorship analysis is also conducted using VOSviewer software to better understand international collaboration in the field of analytical chemistry education research. To this end, countries with a minimum of five studies were included in the analysis, and it was found that 24 out of 65 countries met this criterion. Of these 24, however, only 18 countries were connected. The resulting co-authorship map obtained is displayed in Figure 7.

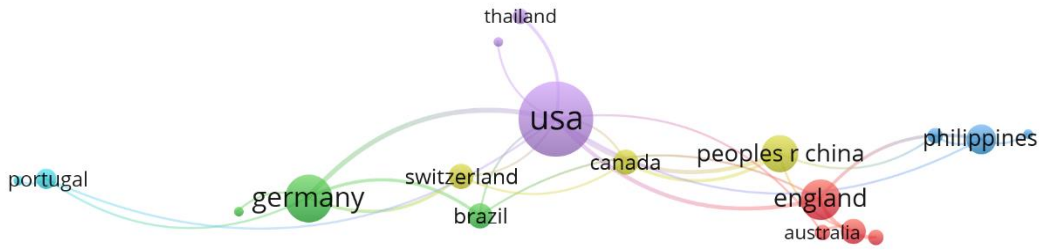

Figure 7. *Co-authorship (unit of analysis: countries)*

Each country is illustrated by a node in the figure. The larger the size of the node indicates the collaboration degree of a country, and the thicker the curve between two countries indicates the degree of cooperation between them. As illustrated in Figure 7, 18 countries are grouped into 6 distinct clusters, with a total link strength (TLS) of 40, which is relatively low compared to some similar studies (Ayna & Şen, 2024; Irwanto et al., 2024). This finding might be attributed to the fact that the United States is the most collaborative country and dominates the research field, accounting for almost half of the TLS (19 TLS), as clearly demonstrated in Figure 7. The figure also shows that, in addition to the USA, the other most collaborating countries are Germany, the UK, China, and the Philippines. However, there is generally weak cooperation among the countries in the figure, as evidenced by the number of link strengths. For example, the link strength between Germany and the USA is 4, between the USA and the UK is 3, and between Brazil and Germany is 2. International collaboration is crucial for researchers to share knowledge and foster global cooperation, which contributes to the advancement of scientific progress (Irwanto et al., 2024).

3.2.4. ***Bibliographic coupling of countries***

Bibliographic coupling is a science mapping method that identifies relationships between publications by grouping them into thematic clusters based on overlapping references, assuming that publications citing similar sources tend to have comparable content (Donthu et al., 2021; Zupic & Čater, 2015). VOSviewer software was used to visualize the bibliographic coupling of countries, applying a minimum threshold of five documents per country. This resulted in a set of 62 countries, 24 of which met the threshold, and the results are presented in Figure 8.

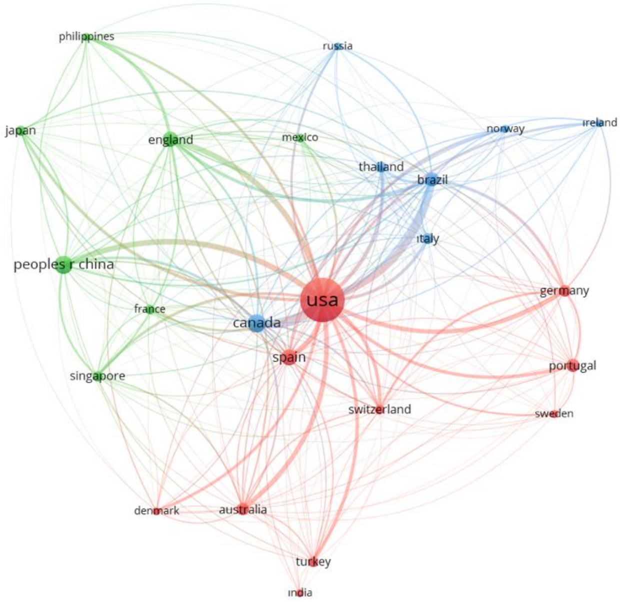

Figure 8. *Bibliographic coupling of countries*

As observed in Figure 8, 24 countries are divided into 6 distinct clusters, with a total of 232 links and a total link strength (TLS) of 8096. The total link strength reflects the combined intensity of the bibliographic coupling ties between a particular country and other countries. Clearly, as shown in Figure 8, the USA “5335 TLS,” Brazil “1683 TLS,” Canada “1253 TLS,” England “1124 TLS,” and China “870 TLS” exhibited the highest total link strengths. The red cluster (Cluster 1) with six countries includes the USA, Australia, Denmark, Turkey, Spain, and India. For example, the link strength between the USA and Australia is 328, between Denmark and the USA is 132, and between Turkey and Spain is 22. England, Japan, the Philippines, and Mexico are in the green cluster (Cluster 2). Germany, Portugal, Sweden, and Switzerland are placed in the dark blue cluster (Cluster 3). Russia, Brazil, Thailand, and Italy are placed in the yellow cluster (Cluster 4). Moreover, cluster 5 (purple) comprises three countries: the People's Republic of China, France, and Singapore. Lastly, Canada, along with Ireland and Norway, is in the blue cluster (Cluster 6). These findings indicate that countries that are likely to have good academic relations among them, regardless of whether they are geographically distant (such as England, Japan, and Mexico) or close (for example, some European countries such as Germany, Sweden, and Switzerland), demonstrate bibliographic coupling. Another significant conclusion that can be drawn from these findings is that the United States occupies a pivotal position in the domain of analytical chemistry education research; in other words, it emerges as the most prolific nation and exhibits strong bibliographic coupling links with all other nations, as illustrated in Figure 8. Similar studies also indicated that the United States was the most contributing country to organic chemistry education research (Hassan et al., 2022; Pabuçcu-Akış, 2025).

3.2.5. ***Co-occurrence analysis of author keywords***

By conducting a co-occurrence analysis of keywords, the pivotal areas of research can be assessed (Martins et al., 2024). Accordingly, the analysis was initiated by selecting 'co-occurrence' as the analysis type and 'author keywords' as the unit of analysis within the VOSviewer software. Initially, a total of 631 keywords were identified. However, due to the presence of similar terms, a data cleaning procedure was applied in which similar keywords were merged into a thesaurus file. After uploading the thesaurus file, a minimum occurrence threshold of eight was applied to the keywords, resulting in 105 out of the 549 keywords meeting the threshold for inclusion in the analysis.

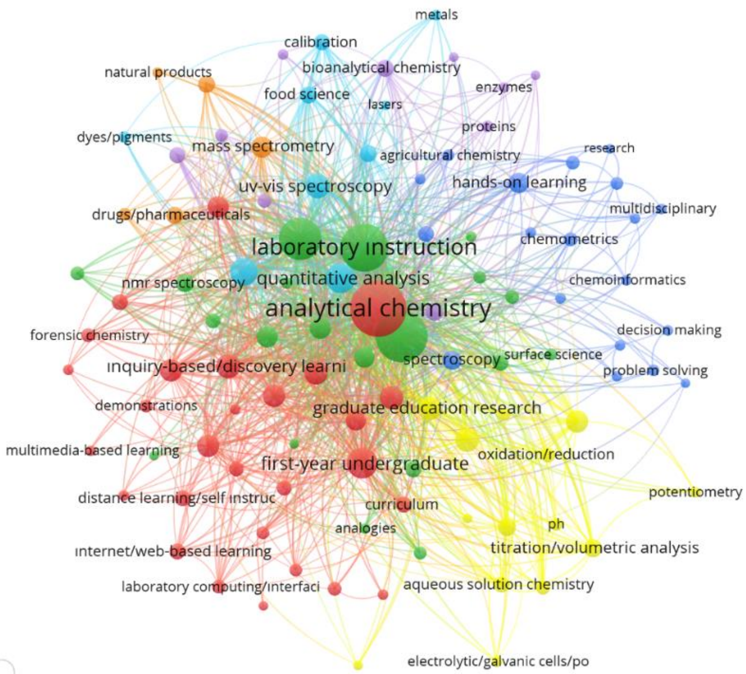

Figure 9. *Author keywords co-occurrence network of analytical chemistry education research*

Figure 9 shows that the keywords are represented by colored circles. The size of the circles is a function of the frequency of their appearance in the titles and abstracts of articles. In other words, the more frequently a keyword appears, the greater its circle and text size (van Eck & Waltman, 2010). The analysis of the co-occurrence network of keywords revealed that the most frequent keywords are: 'analytical chemistry' (641), 'upper-year undergraduate' (537), 'laboratory instruction' (432), 'hands-on learning/manipulatives' (325), 'first-year undergraduate' (141), 'quantitative analysis' (139), 'instrumental methods' (109), 'inquiry-based/discovery learning' (82), 'uv-vis spectroscopy' (80), 'graduate education research' (76), 'computer-based learning' (73), and 'environmental chemistry' (72). These findings indicate that researchers predominantly explored these concepts within the field of analytical chemistry education.

The keyword co-occurrence map presents data through the representation of edges and nodes, wherein a substantial edge signifies a considerable frequency of simultaneous occurrences, and larger nodes denote an elevated prevalence of the keyword (Tiwari et al., 2024). The largest node(s), representing the most frequently occurring keyword(s), were used to identify each cluster. The analysis identified seven major clusters composed of 5 to 28 keywords: "analytical chemistry" (in the red cluster), "upper-year undergraduate" (in the green cluster), "quantitative analysis" (in the light blue cluster), "graduate education research" (in the yellow cluster), "mass spectrometry" (in the orange cluster), "hands-on learning" (in the dark blue cluster), and "bioanalytical chemistry" (in the purple cluster). The keywords chosen to define the clusters are not always identical to the most frequently used keywords, as some of them appear within the same cluster. For example, the most frequently used keywords "upper-year undergraduate" (537) and "laboratory instruction" (432) both belong to the green cluster. Therefore, "upper-year undergraduate" was chosen to represent the cluster.

The first cluster, entitled 'Analytical Chemistry,' comprises 28 items and is dominated by both analytical chemistry education-related keywords, such as “first-year undergraduate,” “inquiry-based learning,” “distance learning,” “computer-based learning,” and “web-based learning,” and analytical chemistry-related keywords, such as “environmental chemistry,” “chromatography,” and “forensic chemistry.” The second cluster, entitled ‘upper-year undergraduate,’ comprises 20 items and is mainly dominated by analytical chemistry and chemistry related keywords such as “NMR spectroscopy,” “IR spectroscopy,” “organic chemistry,” “polymer chemistry,” “nanotechnology,” “surface science,” and “material science” along with “laboratory instruction.” The third cluster, entitled ‘hands-on learning,’ comprises 19 items and is also dominated by both analytical chemistry-related keywords, such as “chemometrics,” “cheminformatics,” “green chemistry,” and analytical chemistry education-related keywords, such as “problem solving” and “discovery learning.” The fourth cluster, entitled ‘graduate education research,’ comprises 14 items and is mainly dominated by analytical chemistry-related keywords such as “physical chemistry,” “electrochemistry,” “titration/volumetric analysis,” “aqueous solution chemistry,” and “potentiometry.” The fifth cluster, entitled ‘bioanalytical chemistry,’ comprises 10 items and is entirely dominated by analytical chemistry-related keywords such as “biochemistry,” “fluorescence spectroscopy,” “proteins,” and “enzymes.” The sixth cluster, entitled ‘quantitative analysis,’ comprises 9 items and is also dominated by both analytical chemistry and chemistry related keywords such as “uv-vis spectroscopy,” “instrumental analysis,” “atomic spectroscopy,” “food science,” and “dyes/pigments.” The last cluster, entitled ‘mass spectrometry,’ comprises 5 items and is also dominated by analytical chemistry-related keywords such as “gas chromatography,” “drugs/pharmaceuticals,” and “consumer chemistry.” These findings indicate that while some studies focus solely on analytical chemistry education, others deal with topics in both analytical chemistry and other areas of chemistry, using approaches based on analytical chemistry education.

4. CONCLUSION, RECOMMENDATIONS AND LIMITATIONS

This study provides an extensive bibliometric analysis of research trends in analytical chemistry education, which covers a period from 2000 to 2024 and is based on the analysis of 742 articles sourced from the Web of Science database. As far as we know, this is the first study of its kind that explores the field bibliometrically. To this end, we conducted performance and science mapping analyses to assess the current landscape of research. The performance analysis focused on publication and citation trends, identifying the most productive countries and institutions, and determining the most influential journals, articles, and authors. The science mapping analysis included co-citation analysis of journals, co-authorship analysis of authors and countries, bibliographic coupling of countries, and co-occurrence analysis of author keywords.

The results indicated a significant rise in the number of publications starting from 2010, with a peak of 81 articles in 2021, despite occasional declines in 2015, 2017, 2019, and 2022. In contrast, the number of citations has shown a steady upward trend, reaching its highest point in 2023 with 1,916 citations. These findings suggested a sustained and growing interest among researchers in the field of analytical chemistry education since 2010. Biblioshiny analysis was used to identify the most productive countries and institutions in the field. The results indicated that, while the USA leads with the highest number of publications (n=1,061), the National University of Singapore stands out as the top institution, making the largest contribution to analytical chemistry education research with 24 publications. Among the 25 journals publishing a total of 742 articles, the *Journal of Chemical Education* emerged as the most active, with 693 publications, followed by *Chemistry Education Research and Practice*, *Biochemistry and Molecular Biology Education*, and *Education for Chemical Engineers*. There is a parallelism between the USA being the leading country in the field and the JCE published in this country being the most influential journal. Results of some similar studies are also consistent with this finding (Hassan et al., 2022; Pabuçcu-Akış, 2025). The most influential article, based on both total citations (TC) and citations per year (TCY), is the paper by Elgrishi et al. (2018). The top three prolific authors were Endler Marcel Borges, who published 9 articles, and James P. Grinias and Fun Man Fung, each with 5 papers. Together, their works account for approximately 2.56 percent of the total articles analyzed. These results indicate that author productivity is not at the desired level.

Bibliometric mapping analysis indicated that the most frequently co-cited journal is JCE, with 7.253 co-citations and 42.219 total link strength. JCE also has the strongest links in terms of co-citation with other chemistry journals and chemistry education journals that have high impact factors in their fields. Performance analysis results also support this finding. The second and the third most frequently co-cited journals were Analytical Chemistry and Chemical Education Research and Practice (CERP) with 511 and 295 citations, respectively. Analytical Chemistry is a journal that has been publishing comprehensive studies in the field of analytical chemistry for many years and has a very high impact factor in the field. CERP, on the other hand, is a relatively new journal compared to Analytical Chemistry, also with a high impact factor in the field of chemistry education, which has been publishing studies on chemistry education since 2000. Therefore, it is not surprising that these journals are prominent in their respective fields.

Co-authorship analysis was conducted to reveal the social interactions among authors contributing to the field of analytical chemistry education research. The analysis showed that 26 authors were gathered in three different clusters. Among these authors, Kreuter, R., Chohan, BS., Skyes, D., and Li, YC were found to be the most collaborating authors. In addition, Table 1 indicates that the international co-authorship rate is very small (7.143%). From this, it can be concluded that there is not much collaboration among authors from different countries and that the existing collaborations are not at the expected level. This finding is parallel to the results of similar studies (Ayna & Şen, 2024; Irwanto et al., 2024; Pabuçcu-Akış, 2025). As a result of the co-authorship analysis conducted to better understand international collaboration between countries, it was determined that 18 countries had weak co-authorship with each other unlike similar studies (Ayna & Şen, 2024; Irwanto et al., 2024). Among these countries, the USA was the country that collaborated the most and dominated the research field. The other countries that collaborated the most after the USA were Germany, England, China, and the Philippines.

The results of the bibliographic coupling analysis showed that 24 countries were gathered in 6 separate clusters. When the countries were ranked according to their total link strengths (TLS), the USA ranked first with "5335 TLS," followed by Brazil with "1683 TLS," Canada with "1253 TLS," England with "1124 TLS," and China with "870 TLS." Examining these clusters revealed that the countries that were most likely to have good academic interactions with one another, regardless of their geographical distance or closeness, were bibliographically matched. In addition, the central position of the USA in the field of analytical chemistry education research was coined again by this analysis. Similar studies also showed that the USA was the country that contributed the most to organic chemistry education research (Hassan et al., 2022; Pabuçcu-Akış, 2025).

The keyword co-occurrence analysis indicated that the 10 most frequent keywords predominantly explored in the field were 'analytical chemistry,' 'upper-year undergraduate,' 'laboratory instruction,' 'hands-on learning/manipulatives,' 'first-year undergraduate,' 'quantitative analysis,' 'instrumental methods,' 'inquiry-based/discovery learning,' 'UV-Vis spectroscopy,' and 'graduate education research.' Based on these findings, it is recommended that researchers in the field of analytical chemistry education focus on the *Journal of Chemical Education*, as it has published the highest number of articles. Reviewing works from prominent authors such as Endler Marcel Borges, James P. Grinias, and Fun Man Fung, who have significantly contributed to the field, would provide valuable insights. Researchers should also consider collaborating with institutions like the National University of Singapore, which ranks highest in institutional contribution. Furthermore, attention should be given to key concepts such as 'laboratory instruction,' 'hands-on learning,' and 'inquiry-based/discovery learning,' as these are the most frequently used author keywords, which emphasize active student engagement and experiential learning, may also reflect a shift in educational practices toward more student-centered methodologies in the teaching of analytical chemistry. Collaborating with researchers from countries with high publication output, particularly the USA, could also enhance the visibility and impact of their research.

Although this bibliometric analysis offers valuable insights into the research landscape of analytical chemistry education, it is important to acknowledge several key limitations of the study. First, we relied solely on the Web of Science database, excluding other relevant sources like Scopus. Second, we limited our focus to academic articles, which means many valuable contributions that could offer additional perspectives from other sources have been overlooked, such as conference proceedings, book chapters, books, theses, and dissertations. Third, while we presented the present status and trends of 742 English-language documents, we did not delve into the detailed findings of each article. To gain a more comprehensive understanding, future studies could expand by including multilingual databases and conducting comparative analyses between regional publication patterns. It is hoped that this study will serve as a valuable guide for researchers interested in the field of analytical chemistry education, providing them with a clear understanding of the existing literature, current trends, and potential areas for further exploration.

Reference

Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics, 11*(4), 959–975. https://doi.org/10.1016/j.joi.2017.08.007

Arifiani, R., & Irwanto, I. (2024). Augmented reality integrated with mobile learning in chemistry education: A Bibliometric Analysis from 2012-2022. *Journal of Educators Online, 21*(2), n2.

Ayna, S., & Şen, Ş. (2024). Kimya eğitiminde sorgulamaya dayalı öğrenmenin bibliyometrik analizi. *Milli Eğitim Dergisi, 53*(243), 1357–1386. https://doi.org/10.37669/milliegitim.1242967

Barbosa, M. L. de O., & Galembeck, E. (2022). Mapping research on biochemistry education: A bibliometric analysis. *Biochemistry and Molecular Biology Education, 50*(2), 201–215. https://doi.org/10.1002/bmb.21607

Benhander, G. M. (2024). Mapping research landscape: Bibliometric analysis of microextraction techniques in drug analysis using scopus database. *Analytical and Bioanalytical Chemistry Research, 11*(2), 211–225. https://doi.org/10.22036/abcr.2024.429932.2013

Birkle, C., Pendlebury, D. A., Schnell, J., & Adams, J. (2020). Web of Science as a data source for research on scientific and scholarly activity. *Quantitative Science Studies, 1*(1), 363–376. https://doi.org/10.1162/qss_a_00018

Bota-Avram, C. (2023). Bibliometric analysis of sustainable business performance: Where are we going? A science map of the field. *Economic Research-Ekonomska Istraživanja, 36*(1), 2137–2176. https://doi.org/10.1080/1331677X.2022.2096094

Cardoso Rial, R. (2024). AI in analytical chemistry: Advancements, challenges, and future directions. *Talanta,* 274, 125949. https://doi.org/10.1016/j.talanta.2024.125949

Christian, G. D., Dasgupta, P. K., & Schug, K. A. (2013). *Analytical chemistry* (7th ed.). Wiley.

Destino, J. F., & Cunningham, K. (2020). At-home colorimetric and absorbance-based analyses: An opportunity for inquiry-based, laboratory-style learning. *Journal of Chemical Education, 97*(9), 2960–2966. https://doi.org/10.1021/acs.jchemed.0c00604

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research,* 133, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Elgrishi, N., Rountree, K. J., McCarthy, B. D., Rountree, E. S., Eisenhart, T. T., & Dempsey, J. L. (2018). A practical beginner's guide to cyclic voltammetry. *Journal of Chemical Education, 95*(2), 197–206. https://doi.org/10.1021/acs.jchemed.7b00361

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A., & Pappas, G. (2008). Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and weaknesses. *The FASEB Journal, 22*(2), 338–342. https://doi.org/10.1096/fj.07-9492LSF

Filgueiras, M. F., de Jesus, P. C., & Borges, E. M. (2021). Quantification of nitrite in food and water samples using the griess assay and digital images acquired using a desktop scanner. *Journal of Chemical Education, 98*(10), 3303–3311. https://doi.org/10.1021/acs.jchemed.0c01392

Fung, F. M., Choo, W. Y., Ardisara, A., Zimmermann, C. D., Watts, S., Koscielniak, T., Blanc, E., Coumoul, X., & Dumke, R. (2019). Applying a virtual reality platform in environmental chemistry education to conduct a field trip to an overseas site. *Journal of Chemical Education, 96*(2), 382–386. https://doi.org/10.1021/acs.jchemed.8b00728

Fung, F. M., & Watts, S. F. (2017). Bird's-eye view of sampling sites: Using unmanned aerial vehicles to make chemistry fieldwork videos. *Journal of Chemical Education, 94*(10), 1557–1561. https://doi.org/10.1021/acs.jchemed.6b00985

Grinias, J. P. (2017). Making a game out of it: using web-based competitive quizzes for quantitative analysis content review. *Journal of Chemical Education, 94*(9), 1363–1366. https://doi.org/10.1021/acs.jchemed.7b00311

Grinias, J. P., & Smith, T. I. (2020). Preliminary evidence on the effect of an open-source textbook in second-year undergraduate analytical chemistry courses. *Journal of Chemical Education, 97*(8), 2347–2350. https://doi.org/10.1021/acs.jchemed.0c00293

Hanifa, W. S., Handayani, S., & Suyanta, S. (2024). Bibliometric analysis: Green chemistry trends and issues in chemistry education from 2019 to 2024. *Jurnal Pendidikan Kimia, 16*(2), 159–167. https://doi.org/10.24114/jpkim.v16i2.58875

Harris, D. C. (2015). *Quantitative chemical analysis* (9th ed.). W. H. Freeman.

Harzing, A. W. (2023). *Using the Publish or Perish software*: *Crafting your career in academia*. Tarma Software Research Limited.

Hassan, N. N., Talib, O., Shariman, T. P., Rahman, N. A., & Zamin, A. A. M. (2022). A bibliometric analysis on how organic chemistry education research has evolved collaboratively over time. *Jurnal Pendidikan IPA Indonesia, 11*(1), 73–90.

He, Y., Swenson, S., & Lents, N. (2012). Online video tutorials increase learning of difficult concepts in an undergraduate analytical chemistry course. *Journal of Chemical Education, 89*(9), 1128–1132. https://doi.org/10.1021/ed200685p

Hupp, A. M., Kovarik, M. L., & McCurry, D. A. (2024). Emerging areas in undergraduate analytical chemistry education: microfluidics, microcontrollers, and chemometrics. *Annual Review of Analytical Chemistry, 17*, 197–219. https://doi.org/10.1146/annurev-anchem-061622-041922

Irwanto, I., Afrizal, A., & Lukman, I. R. (2024). *Research trends in chemistry education: A bibliometric review (1895–2022)*. AIP Conference Proceedings (Vol. 2982, No. 1). AIP Publishing. https://doi.org/10.1063/5.0182936

Kaushik, S., & Kumar, B. (Eds.). (2023). *Analytical methods in chemical analysis: An introduction*. De Gruyter.

Koçak, M., & Soylu, Y. (2023). Examining the general structure of learning environments designed in education: Bibliometric analysis between 1970 and 2022. *Learning Environments Research, 26*(3), 761–783. https://doi.org/10.1007/s10984-022-09452-8

Koh, S. B. K., & Fung, F. M. (2018). Applying a quiz-show style game to facilitate effective chemistry lexical communication. *Journal of Chemical Education, 95*(11), 1996–1999. https://doi.org/10.1021/acs.jchemed.7b00857

Kuntzleman, T. S., & Jacobson, E. C. (2016). Teaching Beer's Law and absorption spectrophotometry with a smart phone: A substantially simplified protocol. *Journal of Chemical Education, 93*(7), 1249–1252. https://doi.org/10.1021/acs.jchemed.5b00844

Mao, S., Fu, L., Yin, C., Liu, X., & Karimi-Maleh, H. (2022). The role of electrochemical biosensors in SARS-CoV-2 detection: A bibliometrics-based analysis and review. *RSC Advances, 12*(35), 22592–22607. https://doi.org/10.1039/D2RA04162F

Martins, J., Gonçalves, R., & Branco, F. (2024). A bibliometric analysis and visualization of e-learning adoption using VOSviewer. *Universal Access in the Information Society, 23*(3), 1177–1191. https://doi.org/10.1007/s10209-022-00953-0

Masania, J., Grootveld, M., & Wilson, P. B. (2018). Teaching analytical chemistry to pharmacy students: A combined, iterative approach. *Journal of Chemical Education, 95*(1), 47–54. https://doi.org/10.1021/acs.jchemed.7b00495

Naese, J. A., McAteer, D., Hughes, K. D., Kelbon, C., Mugweru, A., & Grinias, J. P. (2019). Use of augmented reality in the instruction of analytical instrumentation design. *Journal of Chemical Education, 96*(3), 593–596. https://doi.org/10.1021/acs.jchemed.8b00794

Pabuçcu-Akış, A. (2025). Using innovative technology tools in organic chemistry education: Bibliometric analysis. *Chemistry Teacher International*, *7*(1), 141-156. https://doi.org/10.1515/cti-2024-0055

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71

Pedraja-Rejas, L., Garrido-Tamayo, M.-A., Ortega-Piwonka, I., Rodríguez-Ponce, E., & Laroze, D. (2024). Scientific production in Latin American physics: A bibliometric analysis. *Scientometrics, 129*(7), 4189–4230. https://doi.org/10.1007/s11192-024-05035-x

Research and Innovation Rankings—Singapore 2024. (n.d.). Retrieved December 23, 2024, from https://www.scimagoir.com/rankings.php?country=SGP

Shao, J., Wang, C., Shen, Y., Shi, J., & Ding, D. (2022). Electrochemical sensors and biosensors for the analysis of tea components: A bibliometric review. *Frontiers in Chemistry*, 9. https://doi.org/10.3389/fchem.2021.818461

Shidiq, A. S., Permanasari, A., Hernani, & Hendayana, S. (2021). The use of simple spectrophotometer in STEM education: A bibliometric analysis. *Moroccan Journal of Chemistry, 9*(2), 290-300. https://doi.org/10.48317/IMIST.PRSM/morjchem-v9i2.27581

Sidou, L. F., & Borges, E. M. (2020). Teaching principal component analysis using a free and open-source software program and exercises applying PCA to real-world examples. *Journal of Chemical Education, 97*(6), 1666–1676. https://doi.org/10.1021/acs.jchemed.9b00924

Silva de Souza, R. Jr., & Borges, E. M. (2023). Teaching descriptive statistics and hypothesis tests measuring water density. *Journal of Chemical Education, 100(*11), 4438–4448. https://doi.org/10.1021/acs.jchemed.3c00402

Skoog, D., Holler, F., & Crouch, S. (2017). *Principles of instrumental analysis* (7th ed.). Cengage Learning.

Skoog, D., West, D., Holler, F., & Crouch, S. (2021). *Fundamentals of analytical chemistry* (10th ed.). Cengage Learning.

Soffiantini, V. A. (2021). *Analytical chemistry: Principles and practice*. De Gruyter. https://doi.org/10.1515/9783110721201

Tiwari, A. K., Singh, R., Patel, S. K., Kumar, S., Bhasin, N., Barla, A., & Singh, G. S. (2024). Emerging research trends in river health assessment: A bibliometric analysis. *Anthropocene Science, 3*(3–4), 157–178. https://doi.org/10.1007/s44177-024-00081-9

Tosun, C. (2024). Analysis of the last 40 years of science education research via bibliometric methods. *Science & Education, 33*(2), 451–480. https://doi.org/10.1007/s11191-022-00400-9

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics, 84*(2), 523–538. Scopus. https://doi.org/10.1007/s11192-009-0146-3

van Eck, N. J., & Waltman, L. (2014). Visualizing bibliometric networks. In Y. Ding, R. Rousseau, & D. Wolfram (Eds.), *Measuring scholarly impact: Methods and practice* (pp. 285–320). Springer International Publishing. https://doi.org/10.1007/978-3-319-10377-8_13

Verma, K. K. (2017). Perspective: status and future of analytical chemistry in India. *Analytical Chemistry, 89*(3), 1392–1398. https://doi.org/10.1021/acs.analchem.6b04188

Wenclawiak, B. W., Koch, M., & Hadjicostas, E. (Eds.). (2010). *Quality assurance in analytical chemistry: training and teaching* (2nd ed.). Springer.

Wenzel, T. J., Forbes, P. B. C., Galarreta, B. C., Patel, B. A., Vogel, M., & Wong, D. K. Y. (2024). Incorporation of analytical chemistry in the undergraduate curriculum: Examples from different regions of the world. *Analytical and Bioanalytical Chemistry, 416*(18), 3997–4006. https://doi.org/10.1007/s00216-024-05360-3

World University Rankings. (2024, October 4). Times Higher Education (THE). https://www.timeshighereducation.com/world-university-rankings/latest/world-ranking

Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. *Organizational Research Methods, 18*(3), 429–472. https://doi.org/10.1177/1094428114562629

GENİŞLETİLMİŞ ÖZET

1. GİRİŞ

Analitik kimya, maddelerin kimyasal bileşimlerinin nitel ve nicel analizlerine odaklanan kimyanın önemli bir alt dalıdır. Bu alan temel olarak bilimsel araştırmalar, kalite kontrol süreçleri ve mevzuata uygunluk açısından bir numunenin kimyasal bileşimi hakkında kesin ve doğru bilgilerin üretilmesini içerir (Skoog vd., 2021; Wenclawiak vd., 2010). Öte yandan, bilimsel araştırma ve teknolojik gelişmelerle birlikte hızlı ve doğru analitik sonuçlara yönelik olan talep giderek artmış ve bunun sonucunda spektroskopi, kromatografi, elektrokimyasal analiz, kütle spektrometrisi ve yapay zekâ ile zenginleştirilmiş daha yeni ve sofistike analitik yöntem ve teknikler geliştirilmiştir (Skoog ve ark., 2017; Cardoso Rial, 2024). Analitik kimya eğitimi, geleceğin bu alandaki inovasyonu geliştirebilecek ve yönlendirebilecek uzmanlarının yetiştirilmesinde kritik bir rol oynamaktadır. Bu nedenle, mevcut analitik kimya eğitiminin öğrencilere yalnızca modern analitik cihazları kullanma becerisi değil, aynı zamanda veri analizi ve yorumlama konusunda sağlam bir anlayış ve karmaşık analitik problemleri çözme becerisi de kazandırması gerektiği söylenebilir. Bu ise, analitik kimya eğitiminin güncel ve cazip kalabilmesi için sürekli geliştirilmesi gerektiğini göstermektedir. Diğer yandan, yapılan bazı araştırmalar analitik kimya konularının soyut doğası nedeniyle öğrenciler tarafından anlaşılmakta zorlanıldığını göstermektedir (He vd., 2012; Masania vd., 2018). Bu durumda, analitik kimya eğitiminin geliştirilmesi ve gelişime açık temel alanların belirlenmesi için alanyazındaki ilgili araştırmaların incelenerek güncel eğilimlerin belirlenmesi gerekmektedir. Bunun için bibliyometrik analiz yaklaşımından yararlanılabilir (Donthu vd., 2021). Ancak, ilgili alanyazın incelendiğinde, yalnızca analitik kimya eğitimi araştırmaları üzerine yapılan bibliyometrik bir çalışmanın bulunmadığı, fakat analitik kimyanın ve analitik kimya eğitiminin farklı alanlarına yönelik bazı çalışmalar bulunduğu görülmüştür (Benhander, 2024; Hupp vd., 2024; Mao vd., 2022; Shao vd., 2022; Shidiq vd., 2021; Verma, 2017). Sonuç olarak, analitik kimya eğitimine ilişkin yayınların sayısının giderek artması ve yalnızca analitik kimya eğitimi araştırmaları üzerine odaklanan bir bibliyometrik analiz çalışmasının bulunmaması, mevcut literatürdeki bu boşluğun giderilmesini gerekli kılmaktadır. Bu nedenle, araştırmada 2000-2024 yılları arasında Web of Science veri tabanından ulaşılan ilgili makalelerin bibliyometrik analizi yoluyla analitik kimya eğitimi araştırmalarındaki güncel eğilimlerin belirlenmesi amaçlanmıştır.

2. YÖNTEM

Bu çalışmada, 2000-2024 yılları arasında Web of Science (WoS) veri tabanındaki ilgili makalelerin bibliyometrik analizi yoluyla analitik kimya eğitimi araştırmalarındaki güncel eğilimler belirlenmeye çalışılmıştır. Veri toplama süreci güncel PRISMA standartlarına uygun olarak yürütülmüştür (Page vd., 2021). WoS veri tabanında başlangıçta, "analytical chemistry" OR "instrumental analysis" (Topic) and "education" OR "teaching" OR "instruction" (Topic) aramasıyla hiçbir sınırlama olmaksızın 1399 yayına ulaşılmış; yıl, döküman türü, Wos kategorisi, yayın dili seçimleri yapıldıktan sonra toplam 742 makaleye ulaşılmıştır. Makale verileri, bibliyometrik analizler için tab-delimited ve BibTeX dosyaları olarak kaydedilmiştir. Verilerin analizinde Microsoft Excel, Harzing's Publish or Perish, VOSviewer ve Biblioshiny yazılımları kullanılmıştır. Bibliyometrik analizler, performans analizi ve bibliyometrik haritalama olmak üzere iki aşama halinde gerçekleştirilmiştir. Performans analizi bağlamında; veri setinin betimsel analizi, yayın ve atıfların yıllara göre dağılımları, ülkelerin yayın sayılarına göre dağılımı, kurumların yayın sayılarına göre dağılımı, en etkili dergi, makale ve en üretken yazar analizleri yapılmıştır. Bibliyometrik haritalama bağlamında ise ortak atıf (co-citation analysis), ortak yazarlık (co-authorship analysis), bibliyografik eşleştirme (bibliographic coupling) ve birlikte bulunma (co-occurrence analysis) analizleri yapılarak verilerin görselleştirilmesi sağlanmıştır.

3. BULGULAR, TARTIŞMA VE SONUÇ

Analitik kimya eğitimindeki araştırma eğilimlerini kapsamlı bir bibliyometrik analizle alanyazında ilk defa ortaya çıkarmaya çalışan bu çalışmada dikkat çeken bazı sonuçlara ulaşılmıştır. 2000 ile 2010 yılları arasında neredeyse tamamen yatay seyreden ve birkaç araştırmayı geçmeyen yayın sayısı, 2010 yılından itibaren hızlı bir yükseliş göstermiş, 2015, 2017, 2019 ve 2022'de ara sıra düşüşler yaşanmasına karşın 2021 yılında 81 makaleyle en yüksek sayıya ulaşılmıştır. Diğer yandan, atıf sayısında ise 2010 yılından itibaren istikrarlı bir yükseliş gözlenmiş ve 2023 yılında 1916 atıfla en yüksek sayıya ulaşılmıştır. Bu bulgular, araştırmacıların, 2010 yılından itibaren analitik kimya eğitimi alanına yönelik sürekli ve artan bir ilgi içerisinde olduklarını göstermektedir. Analitik kimya eğitimindeki araştırmalarla doğrudan ilgili olmamakla birlikte kimya eğitiminin diğer alanlarında yapılan bazı bibliyometrik çalışmalar da araştırma sonuçlarımızla paralel olarak en yüksek yayın ve atıf sayılarına 2019-2023 yılları arasında ulaşıldığını göstermiştir (Pabuçcu-Akış, 2025; Arifiani & Irwanto, 2024; Ayna & Şen, 2024).

Yapılan performans analizleri, alandaki en üretken ülkenin en fazla yayın sayısıyla (N=1.061) Amerika Birleşik Devletleri (ABD) olduğunu, National University of Singapore'un ise 24 yayınla analitik kimya eğitimi araştırmalarına en büyük katkıyı sağlayan kurum olarak öne çıktığını göstermiştir. Toplam 742 makale yayınlayan 25 dergi arasında, 693 yayınla Journal of Chemical Education (JCE) dergisinin ise en etkin dergi olduğu, toplam ve yıllık atıf sayılarına göre en etkili makalenin ise Elgrishi ve ark., (2018) tarafından yayımlanan makale olduğu tespit edilmiştir. En üretken yazarların ise sırasıyla dokuz makale yayımlayan Endler Marcel Borges ve her biri beşer makale yayımlayan James P. Grinias ve Fun Man Fung olduğu belirlenmiştir. Bu yazarların toplam yayın sayıları, analiz edilen tüm yayınların yaklaşık %2,56'sını oluşturmuştur. Bu sonuç, yazar verimliliğinin yüksek olmadığını göstermektedir. Diğer yandan, ABD'nin alanda lider ülke olmasıyla bu ülkede yayınlanan JCE dergisinin en etkin dergi olması arasında paralellik gözlenmektedir. Yapılan benzer çalışmalar da bu sonuçları doğrulamaktadır (Hassan et al., 2022; Pabuçcu-Akış, 2025).

Bibliyometrik haritalama analizleri, en sık ortak atıf yapılan derginin JCE olduğunu ve bu derginin yüksek etki değerine sahip kimya ve kimya eğitimi dergileriyle ortak atıf açısından en güçlü bağlantılara sahip olduğunu göstermiştir. Performans analizi sonuçları da bu bulguyu desteklemektedir. Diğer yandan, eş-yazarlık analizi, 26 yazarın üç farklı kümede toplandığını ve Kreuter, R., Chohan, BS., Skyes, D. ve Li, YC'nin en çok iş birliği yapan yazarlar olduğunu göstermiştir. Buna göre, farklı ülkelerden yazarlar arasında çok fazla iş birliği olmadığı anlaşılmaktadır. Bu bulgu, benzer çalışma sonuçlarıyla paralellik göstermektedir (Ayna ve Şen, 2024; Hanifa vd., 2024; Pabuçcu-Akış, 2025). Ülkeler arasındaki uluslararası iş birliğini daha iyi anlamak için yapılan eş-yazarlık analizi ise, benzer çalışmaların aksine (Ayna & Şen, 2024; Irwanto et al., 2024), 18 ülkenin birbirleriyle zayıf bir eş-yazarlık içerisinde olduğunu göstermiştir. Bu ülkeler arasında ABD en çok iş birliği yapan ülke olmuş ve bunu sırasıyla Almanya, İngiltere, Çin ve Filipinler takip etmiştir. Bibliyografik eşleştirme analizi sonuçları ise 24 ülkenin 6 ayrı kümede toplandığını göstermiştir. Ülkeler Toplam Bağlantı Güçlerine (TBG) göre sıralandığında ilk sırayı ABD, sonra sırasıyla Brezilya, Kanada, İngiltere ve Çin gelmiştir. Yazar anahtar kelimelerinin birlikte bulunma analizinde ise, analize dahil edilen 105 anahtar kelimeden en sık kullanılan üçü sırasıyla 'analitik kimya', 'lisans üstü sınıf' ve 'laboratuvar eğitimi' olduğu belirlenmiştir.

Araştırma bulguları doğrultusunda, araştırmacılara JCE ve CERP gibi dergilere odaklanmaları önerilmiştir. Alana önemli katkılarda bulunan yazarların çalışmalarını incelemek değerli içgörüler sağlayacaktır. Araştırmacılara ayrıca, araştırma alanına en büyük katkıyı yapan kurumlarla iş birliği yapmayı düşünmeleri ve birlikte bulunma analizi sonucunda ortaya çıkan kavramlara odaklanmaları da önerilmiştir. Özellikle ABD olmak üzere, yüksek yayın çıktısına sahip ülkelerdeki araştırmacılarla iş birliği yapmak, araştırmalarının görünürlüğünü ve etkisini artırabilir. Sonuç olarak, bu çalışma her ne kadar analitik kimya eğitimi araştırma eğilimlerine önemli bir bakış getirse de 2000-2024 yılları arasında Web of Science veritabanından elde edilen İngilizce yazılmış makale verileri ile sınırlıdır. Gelecekte bu alanda araştırma yapmayı düşünecek konu ilgilileri Scopus gibi diğer veritabanlarını, tezler, kitaplar ve bildiriler gibi kaynakları da araştırma kapsamına dahil edebilirler.

ETHICAL APPROVAL

This is a bibliometric analysis study based on the existing literature. Therefore, it does not require ethical approval from an ethics committee. The study has been conducted in full compliance with all the rules specified in the *Higher Education Institutions Scientific Research and Publication Ethics Guidelines*. None of the actions listed under the section "Acts Contrary to Scientific Research and Publication Ethics" in Part II of the regulation have been undertaken.

CONTRIBUTION OF RESEARCHERS

The author's contribution to this research is 100%.

CONFLICT OF INTEREST

The author declares there is no conflict of interests.